Senior Service College FELLOWSHIP PROJECT

STIMULATING INNOVATION AND ACCELERATING THE DEVELOPMENT OF COMPLEX AND SLOWLY MATURING TECHNOLOGIES THROUGH ADVANCED TECHNOLOGY PRIZE COMPETITIONS

BY

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USAWC CLASS OF 2007

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STIMULATING INNOVATION AND ACCELERATING THE DEVELOPMENT OF COMPLEX AND SLOWLY MATURING TECHNOLOGIES THROUGH ADVANCED TECHNOLOGY PRIZE COMPETITIONS

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ABSTRACT

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STIMULATING INNOVATION AND ACCELERATING THE DEVELOPMENT OF COMPLEX AND SLOWLY MATURING TECHNOLOGIES THROUGH ADVANCED TECHNOLOGY PRIZE COMPETITIONS

It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that... by 2015, one third of the operational ground combat vehicles are unmanned. [1]

The Floyd D. Spence National Defense Authorization Act of Fiscal Year 2001, Public Law 106-398, Section 220

The need for military transformation was clear before the conflict in Afghanistan, and before September the 11th. Here at the Citadel in 1999, I spoke of keeping the peace by redefining war on our terms. The same recommendation was made in the strategic review that Secretary Rumsfeld briefed me on last August -- a review that I fully endorse. What's different today is our sense of urgency -- the need to build this future force while fighting a present war. It's like overhauling an engine while you're going at 80 miles an hour. Yet we have no other choice. Our military has a new and essential mission… To build our future force, the Armed Services must continue to attract America's best people, with good pay and good living conditions. Our military culture must reward new thinking, innovation, and experimentation. Congress must give defense leaders the freedom to innovate, instead of micromanaging the Defense Department…. Every dollar of defense spending must meet a single test: It must help us build the decisive power we will need to win the wars of the future. Our country is united in supporting a great cause -- and in supporting those who fight for it. We will give our men and women in uniform every resource, every weapon, every tool they need to win the long battle that lies ahead. [2]

Speech by President George W. Bush to the cadets at The Citadel on December 11, 2001 following the terrorist attacks of September 11th.

Introduction

The need to support innovation and manage risk affects new products introduced through private sector business. Increasingly, disruptive technologies, environmental standards and regulations, and market competition have driven firms to race to have the first product out there. Failing to be first in innovation may mean the difference between increasing or losing a company's value to shareholders and its corresponding market share. Sustaining a competitive advantage is of the utmost importance. Yet, generally, no one at a company dies because an innovation fails—they may lose their jobs but lives are not at risk. In contrast, slowly developing complex technologies or failed innovations for the military may mean the huge cost of human lives on the battlefield. This difference creates a challenge for innovators and Department of

Defense (DoD) leaders. Products need to be both innovative and proven reliable to operate in harsh military environments while performing various levels of mission complexity. The military increasingly relies on complex technologies that in some cases have not matured to a level that ensures successful major weapons systems program goals will be met. There is a need to bridge the gap between the development of complex and slowly maturing technologies and the military's requirement for reliability beyond initial testing. Advanced technology prize competitions are valuable tools that accelerate the development of complex, and potentially disruptive technologies from concept to operational use for the military.

As part of my Secretary of Defense Corporate Fellows Program, I was assigned to spend a year at a U.S. Fortune 100 Corporation—Caterpillar Inc. The experience allowed me to work and learn in the corporate environment. I was able to observe how an exceptional company solves complex customer issues in the development of new products. My assignment to the New Product Introduction Directorate, Technology and Solutions Division provided unique insights and an understanding of the processes and strategies that Caterpillar Inc. uses in Research and Development and New Product Development to solve problems in conditions similar to what the military has to operate in 24 hours a day, 7 days a week. Some of Caterpillar's rugged, industry-proven products are already in use within the DoD worldwide. Throughout my year in the private sector, I gained a better understanding of the demands of business competition and customer requirements in developing innovative products. My first hand view of the processes that a highly successful company uses to respond to customer and business requirements (Voice of the Customer and Voice of the Business) provided valuable learning applicable to my work in the military and with the DoD.

The goal of the National Defense Authorization Act of Fiscal Year 2001 that one-third of the U.S. ground forces would be unmanned by 2015 relies on complex, disruptive technologies that, in some cases have not matured to a level that would ensure this goal could be accomplished by 2015. The Army continues to transition from the current to the future force while simultaneously fighting the Global War on Terrorism (GWOT) with over 600,000 active and reserve component soldiers today serving on active duty in 76 countries worldwide.[3] The main focus of this transformation has been a conversion to more modular units that are built around a Brigade Combat Team (BCT). This effort has allowed the Army to become more flexible, deployable, capable, and relevant to the DoD. The Future Combat System (FCS) is the Army's modernization program that consists of a family of manned and unmanned systems, connected by a common network that enables a scalable or "modular" force to dominate their adversaries in a complex environment.[4] This transformation is complemented by the modernization initiatives, which focuses on FCS as the central part of the effort along with aviation modernization and over 300 other advanced technology systems. [5] This undertaking is an extremely complex, expensive, risky, high-reward revolutionary transformation. FCS is the Army's first major modernization program since my entry into the active Army in 1985. The FCS program would begin 'spinning out' key technologies to the current force approximately every two years and would provide soldiers with key technologies to deal with the full spectrum of challenges they face fighting in irregular environments today and into the future. Fully equipped brigades will begin fielding in 2015. The FCS program consists of 14 interconnected systems referred to as a 'system of systems' that would allow the U.S. Army to better support the National Defense Strategy and conduct joint multinational operations across the full spectrum of conflict. In light of the current and future operational environments, the 2006 Quadrennial Defense Review emphasized stability and civil support operations as well as the primary focus of major combat operations.[6] The United States Government Accountability Office (GAO) Report to Congressional Committees Defense Acquisitions Assessment of Selected Major Weapons Programs released in March 2006 stated, however, "Since our last assessment of FCS, the program assembled an independent review team to assess critical technologies. Although a few technologies appear to have matured, most have shown either no improvement or are now assessed less mature. None of the FCS program's critical technologies are nearing full maturity." [7]

This paper offers real examples of how advanced technology prize competitions are being used to help mature complex technologies for ground robotic autonomous vehicles, which are a critical part of the FCS program. This supports the goal of the 2001 National Defense Authorization Act. Prize competitions have been used since the 18th century to spur innovation and advance the development of complex and slowly maturing disruptive technologies. The Defense Advanced Research Projects Agency (DARPA) used advanced technology competitions in 2004 and 2005 to rapidly accelerate the integration of multiple complex technologies in robotics for autonomous ground vehicle technology development. The development of these complex technologies is essential to autonomous ground vehicle operations as it pertains to FCS and 'spin outs' for the current force for the U.S. Army and the DoD. This paper will also provide an overview of the Secretary of Defense Corporate Fellows Program. The material explores some of my experiences with innovation as part of the Secretary of Defense Corporate Fellows Program while stationed at Caterpillar Inc. That experience supports the hypothesis for using prize competitions to accelerate slowly developing complex technologies for ground autonomous vehicles for the Armed Forces.

The Secretary Of Defense Corporate Fellows Program

The Secretary of Defense Corporate Fellows Program (SDCFP) was initiated in 1995 under Secretary of Defense William Perry. The program was meant to expose senior military officers to a corporate environment in order to learn new ways to improve, transform, and apply lessons learned from the corporate world to both the operations and business sides of the DoD. The business side of the DoD accounts for approximately two thirds of the overall defense budget. Consequently, the DoD needs effective access to world-class executive level business practices applicable to business transformations in the department. Approximately eight officers (two officers from each military service) spend an academic year assigned to a Fortune 500 or high-tech start-up company instead of attending Senior Service College. Over the past twelve years, 44 civilian corporations or businesses have sponsored corporate fellows to work, train, and observe key enterprise strategies that allow these companies to successfully navigate the global business environment.

The lessons learned during the fellowship are communicated to senior DoD officials through group briefings and through individual projects in the form of research papers. The entire fellowship class briefs DoD senior leadership twice during the program. The first brief is at a mid-way point and initial observations and recommendations are offered. Then a final briefing at the end of the program year focuses on common findings and key recommendations. The briefing opportunities offer fellows direct engagement with senior DoD leaders allowing for direct discussion and feedback.[8]

At the time this paper was written, the Secretary of Defense Corporate Fellows Program homepage could be found on-line at http://www.ndu.edu/sdcfp/sdcfhom.html. This Website includes previous year-end briefings and fellows research papers from the program's 12-year history. Some of the key benefits of the program are to expose future senior DoD leaders to a variety of change, innovation, and best business practices used in today's global business environment. This experience allows those senior leaders to use that knowledge in future assignments to better serve their respective Services and the DoD. They gain insights and understand adaptive and innovative business culture, are able to recognize organizational and operational opportunities, and understand the skills required to implement change. This knowledge assists corporate fellow alumni in motivating innovative change throughout their careers. The 2006-2007 participating companies and locations are: Caterpillar (Peoria, Illinois), Deutsche Bank (London, United Kingdom), DuPont (Richmond, Virginia), General Dynamics (Scottsdale, Arizona), IBM (Fairfax, Virginia), McKinsey and Company (Irvine, California), Microsoft (Reston, Virginia), and Pfizer (New York, New York).[9]

Army Transformation and Competing Fiscal Priorities

Today, the Army is shouldering a large portion of the required operational responsibilities and providing the largest number of forces for the GWOT. At the same time, the service continues to operate in a constrained fiscal environment. The executive and legislative branches of the U.S. government have attempted to fund the operational cost for Iraq and Afghanistan through supplemental appropriations. These supplemental appropriations, however, have not provided adequate funding for future challenges and investments in transformation of the Army. A major portion of the Army's current funding is used for personnel costs, maintaining critical infrastructure, and preparing equipment for deployment around the world in support of the National Defense Strategy. The personnel accounts alone amount to more than 80 percent of the Army's budget. Moreover, President Bush announced in his 2007 State of the Union Address that an additional 65,000 soldiers will be added to increase an additional 12 Brigade Combat Teams (BCT) by 2012. [10] Yet unless dramatic changes are made in future Defense investment for the Army, this expansion to 76 BCTs with approximately 225 Support Brigades would further exacerbate the problem of required resources for both current and future challenges.

One of the key fiscal issues for the Army is the allocation of Defense resources, which has not changed much since the late 1940's, even though there has been a major shift in the focus and emphasis of the National Defense Strategy since September 11, 2001. With the post Cold-War drawdown, the Army's portion of investment has been considerably less than that of other departments in the DoD. The Army has received less than one-fifth while other departments have each received approximately one-third, which does not include another one-fifth that is used for the overall DoD.[11] The supplemental funding that has occurred for GWOT has not enabled the Army to conduct necessary research and procurement that would help posture the organization for future threats and challenges. Consequently, the result of combined budget cuts, inadequate investment for the future, and continuing operational budgetary shortfalls, means the Army's FCS Program scope is reduced. That will delay the schedule of FCS Fielding. The Army has now decided to develop the core capability of FCS with 14 interconnected ("System of Systems") instead of the 18 systems that would provide FCS with full capability. This restructuring of the FCS program is part of a balancing act to ensure that the current force can be adequately equipped while modernizing the future force. These systems are a variety of manned and unmanned vehicles, sensors, launch systems, and unmanned aerial vehicles. The system is now referred to as 14+1+1 subsequent to the deferral of the four systems that were part of the original 18+1+1 system. U.S. Army Major General

Jeffrey A. Sorenson, deputy for acquisition and systems management told Pentagon reporters, "*Clearly we've had to go through a very difficult period here in terms of making sure we can modernize as well as support the current operations and the current force. It was a balancing act with respect to funding priorities in modernization as well as making sure the current force is taken care of*."[12] The four individual systems that are being deferred include: two of the four classes of unmanned aerial vehicles, the heavy armed robotic vehicle system, and the intelligent munitions system that includes an armed sensor suite that allows an area to be controlled without physical troop presence. [13] The second and third order effects of these projected reductions would put at risk the ability to reach the full potential of unmanned systems as envisioned for FCS and will delay the fielding of FCS by another five years, failing to reach the goal to have one third of the Army's ground forces unmanned by 2015. This problem further reinforces the importance of using innovative approaches to accelerate slowly maturing disruptive technologies for the Armed Forces. Through partnering we could drive down research and development costs while getting these critical technologies to the soldier more expeditiously. This could be achieved, and indeed has been accomplished through advanced technology prize competitions such as the DARPA Grand Challenges.

History of Prize Competitions

> *What has been will be again, what has been done will be done again; there is nothing new under the sun. Is there anything of which one can say, "Look! This is something new"? It was here already, long ago; it was here before our time.*[14]
>
> **Ecclesiastes 1:9-10**

Although grants and contracts are the most common source for scientific and technological research today, prize competitions offer awards for specific accomplishments and have played a vital role in the advancing of technology. Prizes were the most common form of funding for scientific advancement in the 18th and 19th centuries. This was particularly true in France, the leading scientific nation of that era.[15] The development of many different complex and slowly maturing technologies, which were thought to be impossible at that time, have led to the acceleration of breakthrough advancements using prize competitions.

One of the most famous prizes in scientific history led to the development of accurate nautical navigation. The discovery was driven by the day's most pressing problem to accurately determine longitude while navigating the open sea on the rolling and tossing deck of a ship. This navigational problem was not a trivial matter to the English Navy or the maritime trade. Skilled mariners had known for over two thousand years how to establish latitude. Accurate positioning on the open sea, however, also required knowing the ships' longitude. In 1714 the British Government offered £20,000 (equivalent to about $2.5 million in today's currency) for any reliable method that allowed ship captains to determine their vessels' longitude within half a degree. Two smaller prizes were offered for innovations less accurate. [16] The Board of Longitude was comprised of scientists and admirals including Sir Isaac Newton and Edmund Halley who oversaw the Prize by Act of Parliament. From 1735 to 1761 an unknown inventor used the "wrong" solution method and developed the winning entry. John Harrison, a successful inventor, constructed his first clock in 1735. He subsequently developed four additional models over the next 25 years. In 1765, the Board of Longitude unanimously concluded, "*the said timekeeper has kept its time with sufficient correctness, without losing its longitude in the voyage from Portsmouth to Barbados beyond the nearest limit required by the Act 12th of Queen Anne, but even considerably within the same*." Finally, with King George III's direct involvement, the English Parliament awarded John Harrison the £20,000 prize.[17]

Great Britain was not alone in their use of competitions to promote innovation. The French Académie des Sciences offered a £2,400 prize in 1783, later raised to £12,000 in 1789 to promote the creation of a synthetic alkali industry used in the production of soap, paper, and glass. Nicolas LeBlanc patented his work in 1791, yet his payment was delayed until Napoleon III awarded the prize money to his heirs in 1855. In 1795 the French government offered a 12,000FF prize to develop a reliable method to preserve food for the French Army. Nicolas Appert developed a process in 1804 and was awarded the prize in 1810 by Napoleon.[18]

The popularity of competitions continued into the 20th century with a number of monetary prizes for innovation especially in the aerospace industry. From 1901 to 1913 there were various airship and airplane prizes and races primarily in Europe. Between the first flight of the Wright Brothers in 1903 and 1929, governments, individuals, newspapers, and corporations offered over 50 major aeronautical prizes. In 1919 a wealthy French hotel owner named Raymond Orteig offered a prize of $25,000 to the first person to fly a plane non-stop between Paris and New York. It took eight years before Charles Lindbergh, a relatively unknown American airmail pilot, climbed into the cockpit of the Spirit of St. Louis and flew solo for 30 hours to win the prize on June 16, 1927. Lindbergh beat several already famous pilots who attempted to win and failed. Nine teams spent over $400,000 trying to win a cash prize only a fraction of the amount they had invested in their attempts. Lindberg's success immediately made him a national hero. As a result, air flight took off and the value of aviation skyrocketed. Pilot licenses in the U.S. increased over 300 percent and the number of licensed aircraft in the U.S. increased by 400 percent. The number of airline passengers jumped from 5,782 in 1926 to

173,405 in 1929. [19] Lindbergh's transcontinental flight opened a new era for transportation and helped spur a $300 billion commercial aviation industry in the United States.[20]

Dr. Peter Diamandis worked with the Ansari family and was responsible for the resurgence in the use of prizes as incentives for breakthrough technologies. Dr. Diamandis and the Ansari family created the "X-Prize" in 1996 as an attempt to encourage a radical breakthrough in the advancement of human spaceflight. By that time, innovation in spaceflight had been stalled for over 40 years. [21] The Ansari Foundation describes the X-Prizes as follows, *"An X PRIZE is a multimillion dollar award given to the first team to achieve a specific goal set by the X PRIZE foundation, which has the potential to benefit humanity. Rather than awarding money to honor past achievements or directly funding research, an X PRIZE incites innovation by tapping into our competitive and entrepreneurial spirits."*[22] The X PRIZE began its first competition with the Ansari X PRIZE to facilitate a revolution in private spaceflight. The long-term goal of the Ansari foundation was to make space travel safe, affordable, and accessible to everyone through the creation of a personal spaceflight industry. This prize jump-started 26 teams from seven different nations to pursue radical breakthroughs in the advancement of human spaceflight while pursuing their passions by competing for the prize. On October 4, 2004, aerospace designer Burt Rutan and financier Paul Allen led the first team to design, build and launch a spacecraft capable of carrying three people to 100 kilometers above the earth's surface. The X Prize Foundation awarded the $10 million Ansari X Prize to Mojave Aerospace Ventures for their successful flight.[23] This competition, as with others, required over ten times the amount of the prize winnings to compete. This highly successful spaceflight changed the public's perception of spaceflight and has created significant developments in the personal spaceflight industry. The Ansari Family commented on the results of the X Prize by saying, "*Becoming Title Sponsor of the X Prize has been the best philanthropic investment we have ever made. The result was a world changing accomplishment that captured the heart[s] and mind[s] of young and old across the globe…*"[24]

Prize competitions were also responsible for generating interest in innovation promoting a healthier environment. In 1992, a group of U.S. electric utility companies announced a prize of $30 million that would be awarded to the most energy efficient refrigerator design that did not use harmful CFC refrigerant. This prize sought to enhance environmental quality and energy efficiency. There were over 14 manufacturers that submitted entries to compete. Whirlpool Corporation was selected as the winner for developing a refrigerator that used 25 percent less energy than the most energy efficient model available pre-contest. In fact, Whirlpool's final design used 40 percent less than the Federal energy efficiency standard for new refrigerators.[25]

Even though Whirlpool won the competition, the market conditions did not support these super-efficient refrigerators due to tumbling energy prices in the 1990s. Consumers were unwilling to pay higher market prices for these super-efficient appliances; consequently, Whirlpool stopped production of these appliances by the late 1990s. Additionally, lobbyists from the American Home Appliance Manufacturers trade group were able to successfully delay the new efficiency standards until 2001.[26]

Recently, the U.S. government also started to play a role in innovation through competition. The National Academy of Engineering conducted a blue ribbon workshop in 1999 titled, "Concerning Federally Sponsored Inducement Prizes in Engineering and Science." The workshop made the following recommendation, "*Congress should encourage federal agencies to experiment more extensively with inducement prize contests in science and technology*."[27] Section 2374a of Title 10 of the United States Code authorizes "*The Secretary of Defense, acting through the Director of DARPA, may carry out a program to award cash prizes in recognition of outstanding achievements in basic, advanced, and applied research, technology development, and prototype development that have the potential for application to the performance of the military missions of the DoD*."[28] Accordingly, DARPA became the first federal agency to use the Congressional prize authority to establish a major prize competition based on the National Academy of Engineering's recommendations. The opportunity to compete for major prize competitions has increased over time. Trends in this century suggest that the number of these competitions will continue to grow. Already the number of contests in the 21st century has almost reached the competitions held throughout the entire previous century. The following prize competitions were conducted between 1714 and 2004 and were described in a previous paperSuperparanumonly:[29]

1. ***18th and 19th Centuries Prizes***
   - *The British Longitude Prize*
   - *The Alkali Prize*
   - *The Food Preservation Prize*
2. ***20th Century Aeronautical Prizes***
   - *The Deutsch Prize*
   - *The Daily Mail English Channel Crossing Prize*
   - *The Milan Committee Prize*
   - *The Daily Mail Trans-Atlantic Prize*
   - *The Hearst Prize*
   - *The Orteig Prize*
   - *The Kremer Prizes*
3. ***21st Century Prize Competitions***
   - *The Cheap Access to Space Prize*
   - *The ANSARI X Prize*

- *Defense Advanced Research Agency (DARPA) Grand Challenge*
- *The Feynman Grand Prize*
- *The Methuselah Mouse Prize*

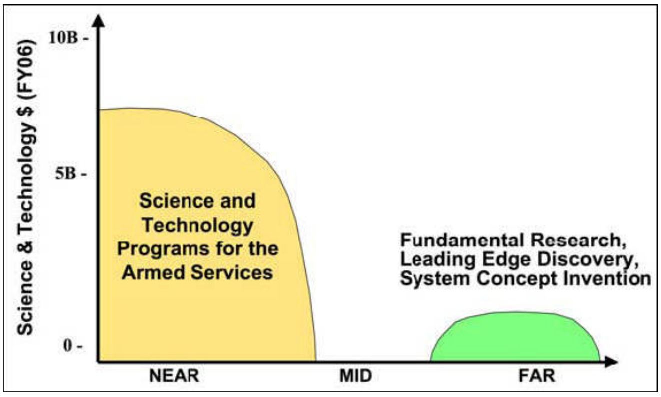
<u>Overview of DARPA</u>

DARPA plays a unique role within the DoD and is independent from the military Services. This independence coupled with some distinctive capabilities, management philosophy, organizational structure, innovative culture, and agile decision making capabilities allows DARPA to pursue higher risk, higher payoff research and development programs and projects. One of the keys to maintaining an entrepreneurial atmosphere is demonstrated in the way DARPA hires their program managers and technical staff. Congress has granted DARPA the ability to use an experimental personnel authority to rapidly hire highly qualified program managers from industry at competitive salaries. Additionally, program managers are generally hired for a four to six year period, which provides the organization with fresh ideas without the risk of becoming focused on protecting programs and their own existence within their organization. Consequently, employees' entrepreneurial spirit, instead of self-preservation, motivates them to pursue high-risk ideas even if there is a good chance the idea will fail. This management philosophy coupled with their innovative culture allows program managers to make rapid decisions about continuing existing programs and starting or stopping other projects based on the continuously adaptive, asymmetric environment of the 21st Century. DARPA also has minimal overhead and owns no laboratories, which further provides flexibility in the executions of its mission. [30] All of these unique organization flexibilities and capabilities allow DARPA to remain strategically and operationally agile while focusing on far-reaching and potentially disruptive innovations for our national security.

While the services need to focus on near term needs and present requirements, DARPA can focus on sweeping innovation to drive major change in the DoD. DARPA is considered the "technological engine" for the transformation of the DoD and looks beyond the immediate service requirements. In DARPA's 2007 Strategic Plan, John Chambers, the editor for The Oxford Companion to American Military History stated that military historians have accurately noted, "*None of the most important weapons transforming warfare in the 20th century – the airplane, tank, radar, jet engine, helicopter, electronic computer, not even the atomic bomb – owed its initial development to a doctrinal requirement or request of the military*."[31] DARPA also noted that they would add more recent technologies to the list such as: unmanned systems, stealth, global positioning system (GPS), and Internet technologies.[32]

Figure 1 illustrates science and technology (S&T) funding for the DoD depicted over time in the near, mid, and far term areas of research, leading edge discoveries, and system concept inventions. [33] The near term S&T funding represents a majority of funding for Service S&T organizations. This focus is due to the current requirements of today's warfighter while the far term fundamental research is where new ideas and far-reaching concepts are created. As the illustration shows, the amount of funding in the far term area is much lower than in the near term S&T. It is much harder to obtain funding for new science and potentially disruptive technologies than for S&T to solve current known problems. This imbalance can explain the failure to develop innovation in the past that led to technological surprises—like the Soviets entering space ahead of the U.S. in 1957. This technological shock drove changes in how the U.S. set the strategic conditions to accelerate far-reaching and leading edge discoveries, which in turn led to DARPA's creation.[34]

Figure 1

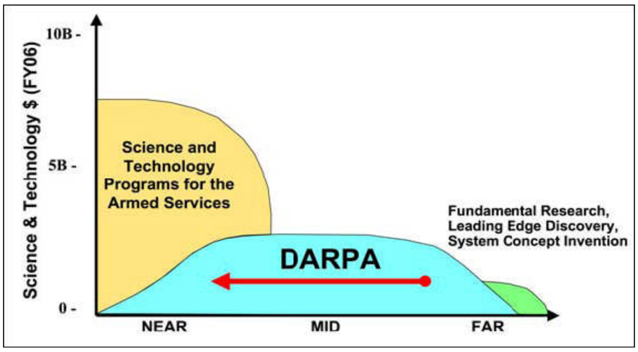


Source: Defense Advanced Research Projects Agency, February 2007

The launching of the Sputnik in 1957 was a signal to the entire world that the Soviets beat the Americans and entered space first. President Eisenhower created DARPA in response to this hi-tech bombshell in 1958. Today, DARPA has a dual mission to prevent technological surprise, while ensuring that the U.S. is able to create technological surprise for our enemies. DARPA sponsors research that focuses on "revolutionary, high-payoff" research to bridge the gap between fundamental discoveries and their military use.[35]

Figure 2 illustrates DARPA's role in S&T and how the organization assists the Services in bridging the gap between near far term discoveries. [36] DARPA's work in high-risk high-payoff fundamental research, and leading edge discoveries, facilitates the transition from fundamental discoveries to actual military use. DARPA's ability to rapidly change also provides the Services the agility to react to emerging threats during conflict situations such as Iraq and Afghanistan. DARPA's senior leadership and program managers

Figure 2



Source: Defense Advanced Research Projects Agency, February 2007 meet frequently with senior civilian and military leaders (military bases, commands, training centers, and other facilities) to gain an understanding of the challenges they face in the current operational context. This engagement strategy allows DARPA to mine the far side research and bridge the gap in what is currently being done and what might be done. [37]

One of the most recent examples of this is the work that DARPA has been involved in with the FCS Program for the DoD on autonomous robotic ground vehicles. DARPA has a cooperative agreement with the Army to assist in developing key technologies for the FCS program. There are two key drivers for developing autonomous ground vehicles for the Armed Forces. The Floyd D. Spence National Authorization Act for fiscal year 2001 established the benchmark that the Armed Forces achieve the fielding of one-third of the operational ground combat vehicles being unmanned by 2015. Second, the urgent operational needs of the current fight require the Army to accelerate transformation and the development of the FCS program including "spin outs" to the current force. These operational requirements reinforce the urgency to respond to the unprecedented challenges to our national security by accelerating slowly developing, disruptive technologies such as robotics and autonomous vehicles for use by the Armed Forces. Prize competitions offer a way to rapidly transition slowly developing and complex technologies and accelerate the transformation of the Army's FCS program as it pertains to robotic and autonomous vehicles.

The DARPA Grand Challenge

DARPA continued to evolve over the years and in 2002, DARPA Director Dr. Anthony Tether envisioned stretching the program to bridge the gap between fundamental discoveries and their military use with innovative and new ideas generated from reaching out to nontraditional sources beyond the established defense community. "*Our goal was to attract a diverse mix of disciplines and personalities that reflect the innovative spirit of the Grand Challenge program, and we have succeeded in our quest," said Dr. Tether. "By bringing together leaders in business, defense, technology and academia with nontraditional partners in fields such as robotics, entertainment and off-road racing, we sought to develop synergies that would foster new ways of thinking.*" [38] The development of the autonomous robotic ground vehicle technology is an example of one of the projects DARPA sought under Dr. Tether's leadership.

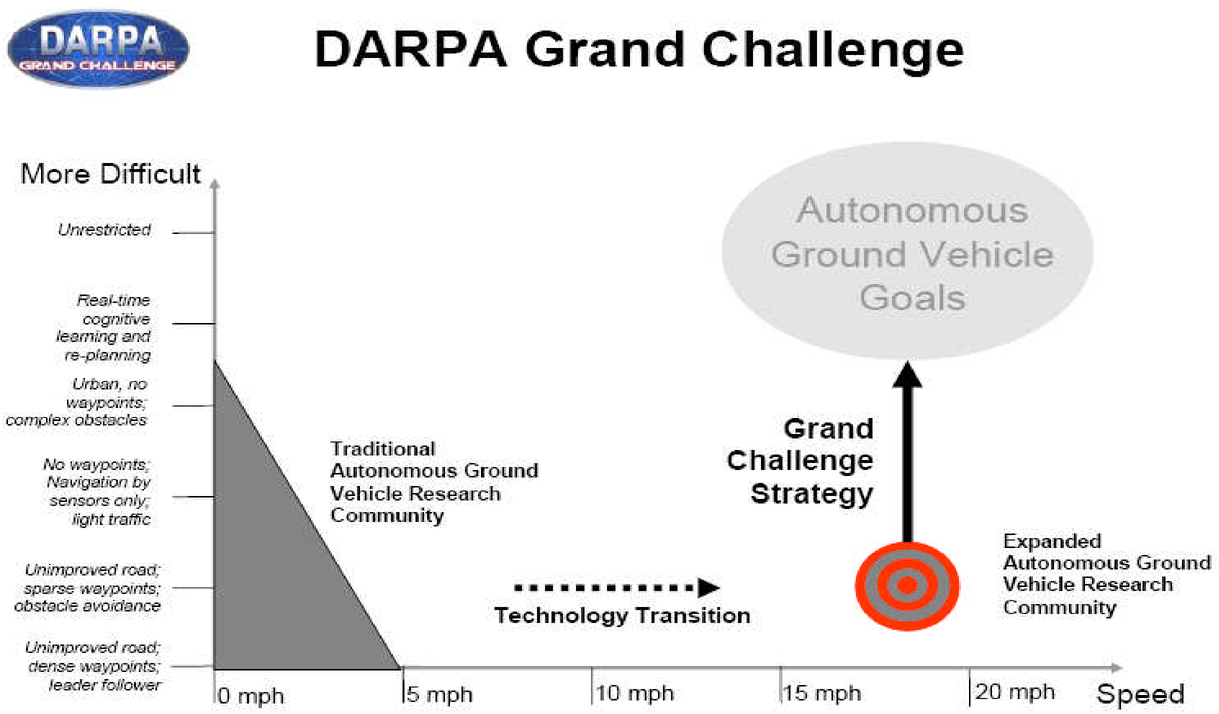
The 2004 DARPA Grand Challenge program offered a $1M prize for the fastest autonomous vehicle to complete a challenging 140-mile course in less than 10 hours over complex desert terrain. The basic framework for the challenge was, "*entries must be* *unmanned, autonomous ground vehicles that cannot be remotely driven*."[39] There were a series of qualifications leading up to the Grand Challenge to ensure that vehicles were technically capable of navigating and avoiding obstacles. Additionally, all vehicles were subjected to thorough inspections to meet the competition's safety and performance requirements. Out of the 106 initial entrants, 15 autonomous robotic vehicles started the competition on March 13, 2004 and none completed the race. The most successful vehicle made it seven miles of the 140-mile course before it crashed. The $1 million prize offered in 2004 went unclaimed because none of the competitors successfully completed the race. Even though the results of the race were not that seemingly impressive, the 2004 Grand Challenge was viewed as an overwhelming triumph because of the interest and excitement it created. [40]

The Under Secretary of Defense for Acquisition, Technology, and Logistics determined that the Grand Challenge concept was promising and following the 2004 DARPA Grand Challenge, authorized an increase in the grand prize to $2 million for the fastest vehicle capable of completing the course. The DARPA Grand Challenge 2005 was again held in the desert and consisted of a 132-mile course through complex terrain to be completed in less than 10 hours. The 132-mile course was chosen as a typical military logistics re-supply mission to determine if autonomous ground vehicles could successfully navigate in complex terrain at realistic speeds of 15-20 mph.[41]

The number of applicants for the 2005 DARPA Challenge surprised officials at DARPA. Even though the technical difficulty of the initial Grand Challenge was clearly demonstrated in 2004, the actual number of applicants nearly doubled from 106 in 2004 to 195 teams in 2005. The team make-up also varied widely. University sponsored teams led by major schools such as the California Institute of Technology, Carnegie Mellon, Stanford, and other notable universities participated in the challenge. The astonishing part was some of the competitors came from ad hoc groups comprised of racing teams such as Tartan Racing, and Insight Racing. The teams were made up of both high and low technical members contributing to the overall team effort. Even one high school team from South Lebanon, Ohio made the first cut for the DARPA Grand Challenge led by a volunteer who had extensive experience in the avionics industry.[42] Additionally, team sponsorship included auto manufacturers such as Volkswagen, and defense contractors such as Oshkosh Truck Corporation.

Figure 3 illustrates the Grand Challenge strategy and the overall autonomous ground vehicle goals as it pertains to technology transition and required ground speeds.[43] The challenge was to transition the traditional autonomous ground vehicle research from less than five mph to more realistic speeds of 15-20 mph. The DARPA Grand Challenge became the tool that allowed DARPA to reach outside the traditional autonomous ground vehicle research community to an extended community that included participants from the research and development community, industry, government, the Armed Services, academia, professional societies, students, backyard inventors, and automotive enthusiasts.[44]

Figure 3



Source: Defense Advanced Research Agency, December 2005

There were 195 initial applicants from 36 states, and three foreign countries for the 2005 Grand Challenge. The key events leading up to the final race consisted of a series of qualifications to narrow the field of competition down to 23 final competitors. This time five autonomous vehicles successfully completed the race. Four of the five vehicles were able to complete the race in less than 10 hours. The top vehicle, Stanford University's Stanley completed the course in six hours and 53 minutes at an average speed of 19.1 mph. Three other vehicles successfully completed the course in seven hours and 4 minutes, seven hours and 14 minutes, and seven hours and 20 minutes with average speeds of 18.6, 18.2, and 17.5 mph, respectively.[45] The competition was an absolute success. The photo on the right is the starting line for the 2005 DARPA Grand Challenge that shows the top three vehicles that successfully completed the autonomous robot race.[46] Caterpillar sponsored three of the five top vehicles that successfully completed the 2005 DARPA Grand Challenge.

Source: Caterpillar Inc. October 2005 "Reprinted Courtesy of Caterpillar Inc."

DARPA met and exceeded its goals fulfilling one of the key elements of their overall strategy to cultivate entrepreneurial performers from universities and industries by funding ideas that represent revolutionary technical achievements. Additionally, the event received widespread mass media coverage throughout the competition. The national and international media coverage was key in connecting the public to an increased awareness about autonomous vehicle technology and the DoD's interest in unmanned vehicles. The depth and breath of media coverage for this event was tremendous. All major U.S. news outlets, news organizations throughout Europe and Asia, broadcast agencies that included CNN and The Discovery Channel as well as the Public Broadcasting Service's NOVA program covered the event.[47] The winner of the race was a modified Volkswagen Toureg from Stanford University's artificial-intelligence lab. The car became a minor celebrity and was put on display in the Smithsonian during the summer of 2006 to highlight the outstanding achievement in robotics.[48]

The DARPA Urban Challenge

DARPA developed plans to sponsor another contest—the 2007 Urban Challenge, which would require revolutionizing autonomous vehicles to operate safely and maneuver in the presence of other moving vehicles. Autonomous vehicles would compete in 60 miles of urban driving in which they had six hours to complete a series of missions. The vehicles would be tested on their ability to navigate autonomously through street traffic—ranging from u-turns, curbs, and intersections, to parking maneuvers, obstacle fields, and lane activities, all while obeying the rules of the road. Awards would be given to the top three finishers of the DARPA 2007 Urban Challenge. First Prize is $2 million, second Prize is $500,000, and third prize is $250,000. [49]

One of the key drivers behind the 2007 Urban Challenge is DARPA's support for the U.S. Army's FCS program. The FCS program has billions of dollars earmarked for the development of manned and unmanned aerial and ground vehicles. Today in Iraq and Afghanistan, there are miniature aerial drones and robots being used to sniff for explosives and, de-arm and destroy Improvised Explosive Devices (IED) commonly seen on the battlefields of 21st century. The stated goal of the 2007 DARPA Urban Challenge is as follows: "*Unmanned ground vehicles must be able to safely operate and maneuver in the presence of other moving vehicles to realize their potential to revolutionize military ground operations. The Urban Challenge will accelerate progress in this area through demonstrations of autonomous unmanned ground vehicles driving safely in a mock urban area with other moving vehicular traffic*".[50]

DARPA reported in their 2007 Strategic Plan that intelligence analysts believe by 2025 nearly 60 percent of the world's population will live in urban areas. Based on these predictions, U.S. forces will likely continue to be deployed in urban areas for operations. These urban areas give our adversaries the ability to conceal movement, weapons, and activities while allowing time to recruit, train, and develop asymmetric capabilities.[51] Urban environments allow our enemies to counter U.S. Forces' conventional capabilities in complex terrain as evidenced in Lebanon, Somalia, Afghanistan, and Iraq. Most recently, the insurgency in Iraq highlights this dilemma and shows how these urban counterinsurgency operations can be very chaotic, dangerous, and costly operations in terms of human casualties.

With the increased pressure to reduce exposure of ground troops to a harmful urban environment, the focus for the DARPA Urban Challenge is lessening the logistical footprint and reducing the number of logistical soldiers required to drive re-supply vehicles through operational environments such as Iraq. Colonel Michael A. Powell, Chairman of the Army

Driving Task Force stated, "*In FY 04, the Army experienced a total of 269 Soldier fatalities; 73% of these fatalities were the result of accidents that occurred behind the wheel of a vehicle. In the on-going Global War on Terrorism, our forces are distributed and fight throughout the Area of Operations. Vehicle operation and convoy operations are no longer administrative tasks but essential mission tasks critical to the war fight. Recognizing this fundamental change, prepare/operate a vehicle in a convoy was made one of the core Warrior tasks.*"[52]

The 2007 Urban Challenge sparked a strong interest among an expanded autonomous research community that includes involvement from many diverse organizations, institutions, and industries. Even U.S. auto manufacturers are actively participating in the 2007 competition with hopes of spin-off benefits stemming from their involvement. As evidenced in the 2004 and 2005 DARPA Grand Challenges, the synergistic effect of bringing together diverse teams from across various organizations with unique capabilities created an environment that has rapidly transformed research and development for autonomous vehicles. Additionally, worldwide media coverage of the upcoming Urban Challenge event is tremendously positive with over 170 articles written about the upcoming race since 2006.[53] DARPA is issuing research grants valued up to $1M for 11 of the 78 most promising teams worldwide.[54] The prize money remains the same as in 2005 ($2 Million) yet there is increased interest in the contest.

DARPA's 2007 event raises the bar for what the organization hopes to accomplish in the Urban Challenge series. Dr. Sebastian Thrun, the creator and leader of the Stanford University's team vehicle (Stanley) that won first place in the 2005 Grand Challenge commented on Stanley's capabilities and admitted the vehicle would have little chance to win in the next competition. "He is a reactive machine that has no planning capability," says Dr. Thrun. "When he saw an obstacle, he was programmed to persist."[55] The 2007 competition, however, will require competitors to operate autonomously in an inhabited urban environment to successfully interface with other traffic. The robotic vehicles must obey speed limits and traffic signals as well as normal driving tasks such as merging, passing, avoiding obstacles, and parking.

There are several autonomous features that have recently been added to automobiles to enhance drivability and safety. These include adaptive cruise control, traction control, and drive by wire steering systems. These features focus on control. The requirements of this year's race, however, require the vehicles to sense where they must go without depending solely on GPS navigational aides. In the past two races, teams that relied exclusively on GPS navigation often faced confrontation with interference that included concrete barriers, trees, bridges, and overhead power lines. These kinds of obstacles often corrupt the GPS readings.[56] The use of a suite of sensors and other devices such as radar, LIDAR, inertial measurement systems, and cameras to create complementary and enhanced capabilities that work together to assist in guiding the vehicles through a complex urban environment is the goal.[57]

The Urban Challenge will be held at an undisclosed location in the western U.S. on November 3, 2007. There are two options for competitors in the 2007 Urban Challenge. Track A allows participants to submit proposals that will provide up to $1M per team based on specific guidelines established by DARPA. Track A establishes four milestones that would allow DARPA to determine the research grant award payout amount based on their assessment of milestone accomplishment. The teams that successfully accomplish Milestone 4 will be qualified the Urban Challenge final event. Track B is the alternative. Track B allows teams to participate by providing a video that is evaluated by DARPA and followed by a site visit. There is a direct correlation between the success of a team and the results of its video. The site visit allows the teams to demonstrate that their autonomous vehicle meets standardized criteria. Following a successful site visit, triumphant teams in Track B will be allowed to compete in the National Qualification Event (NQE). DARPA then determines which teams should advance to the final event for the Urban Challenge and join the winning teams from Track A that successfully achieved Milestone 4.[58] Caterpillar Inc. is sponsoring three teams (Team TerraMax of Oshkosh Truck Corporation, Carnegie Mellon Tartan Racing and Victor Tango of Virginia Tech) to participate in the DARPA 2007 Urban Challenge. These three teams have also qualified for research funding up to $1M.[59] The DARPA Urban Challenge will provide tremendous benefits for the furtherance of the autonomous ground vehicle research and development program and the Army's FCS program. The fact that talent continues to participate, despite the low prize money, speaks to the solid interest the competition alone attracts. These competitions have in the past and will likely continue to produce many direct and secondary benefits for years to come.

Direct and Spin-off Benefits of Prize Competitions

> *"Prizes work!" "But if they are to produce real and revolutionary results, they need to be clear, challenging, and exciting enough for people to invest their time and money to win."*[60]
>
> **Rick Tumlinson, Founder Space Frontier Foundation**

There are various methods of acquisition that could be used as procurement instruments for the development of technology through research. For example, grants and contracts are the most commonly used method to further research and technology development. These methods, however, are subject to a number of biases based on a set of requirements usually found in the statement of work. This is where the biases can come into the process based on limited technical competency, time available, and overall level of effort from the selection team. The nature of the contracting process itself and the rapid developments in technology cannot guarantee that the best contractor or grantee is selected. These acquisition officials must use their best professional judgment to determine which proposal will work the best for a given set of requirements. Consequently, there is still some areas of the overall process that are not completely clear and require a certain amount of professional judgment to determine which proposal will best fulfill the contract proposal. These selections can be influenced and skewed by preconceived notions about a certain requirement or technology thereby creating a predetermined solution. In prize competition methodology, there is no requirement to try and best guess what the future state will be. The prize competition rules, if written objectively and correctly will not provide a predetermined outcome or favor one participant or another. In prize competitions, the participating team must fulfill the goals (less restrictive than contractual requirements) before winning the prize. The prize team does not have to deal with some of the uncertainties that are required in grants and contracts.[61]

The results of prize competitions, as has been shown in previous competitions, however, cannot guarantee a successful completion by any of the competitors. These prize competitions usually have a "first to demonstrate" in the prize rules which may or may not be met in accordance with the prize competition rules. This was true with the Orteig prize for the transatlantic flight when the 1924 deadline was not met by any of the competitors. The prize deadline was extended for an additional five years, which allowed the competitors to continue to demonstrate their performance and eventually win the prize. Charles Lindberg finally won this competition in 1927. The same is true for the original DARPA Grand Challenge as there was no winner in the first competition. It is also possible for multiple teams to meet the minimum prize requirements, as was the case in the 2005 Grand Challenge when five teams successfully completed the race with 4 teams meeting all the requirements in accordance with the prize competitions rules. The key benefits from prize competitions are that the designs and methods used will be very diverse and not constrained by the requirements found in a request for proposal. Most technical problems have multiple conduits for resolution. Prize competitions allow for multiple solutions to the same technical challenge when compared to research grants and contracts.[62] Prize competitions create a certain synergy where the sum of the parts is greater than each individual piece, in this case the technical solution(s).

Table1: A Comparison of Procurement Instruments: Contracts and Grants vs. Prizes [63]

Table 1

Item	Contracts/ Grants	Prizes
Selection Process	"Crystal Ball" – Prejudges which competitor has the best chance of success	"Darwinism" – All competitors compete until end of contest
Results	One possible per contract	Many possible
Successful Delivery	Depends on the ability to select the best competitor	Depends on the ability to formulate achievable rules
Eligibility	Companies able to navigate contracting regulations	All U.S. citizens (some exceptions), non-Federal employees
Cost to NASA	Rarely less, and often more than 100% of costs	A fraction (<20%) of total costs
Payment of Funds	Most funding paid out before delivery of hardware or service	Payment ONLY after successful demonstration of hardware or service.

Participants in prize competitions do not enter these events because it is a great opportunity solely for name recognition, patriotism, or other intangible reasons. Private sector industries, consultants, and universities that participate in prize competitions like the DARPA Grand Challenge are trying to find some near-term economic follow-on opportunities. Competitors can utilize these opportunities to mature a technology or suite of technologies to solve technical challenges that are either preexisting or develop new technologies that may provide a competitive advantage for future products in their industry sectors. The most successful prize competitions use this "win-win" methodology to produce a capability that can be applied to future products, or another commercial market. This methodology can create synergy for multiple market applications like the DARPA Grand Challenges have for the manufacturing and machinery industry, the automotive industry, defense contractors, and universities alike.[64] Additionally, commercial advances are aiding in the rapid acceleration of autonomous technologies that have multiple applications across several industry sectors. For example, U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) is leveraging approximately 80% of the products that it uses in communications systems for autonomous ground vehicles from the commercial sector. There are many commercial solutions now available that are ruggedized off the shelf and require minimal changes to implement. Commercial displays are also being used that makes the operational environment much easier for operators to remain in a protected area instead of being exposed by a window with line of sight visual requirements. By leveraging commercial-off-the-shelf applications for a majority of these systems, the net effect is that costs are driven down and better utilize the benefits of the commercial sector's efficiency, production, and distribution means.[65] The results can be highly functional commercial solutions without the constraints and onerous military specifications (MILSPECS) and government contracting requirements that can create the conditions for the proverbial $500 hammer or the "golden toilet seat". Commercial procurement also allows companies that are not Department of Defense contractors, and do not specialize in systems integration, to provide their commercial solutions to the military.

Prize competitions can also garner extreme interest due to the cultural aspects of the competitions. Ken Davidian in his research titled "*Prizes, Prize Culture, and NASA's Centennial Challenge*" identified seven characteristics of the prize culture. [66]

- ***Democracy*** *– anyone can participate and, potentially, win. Prize competitions are a good way to identify and solicit ideas from previously unknown sources of technical innovation. In contracts, typical government contracts and grants rely on a proposal selection process widely advertised among known (traditional) sources of innovation (e.g. industry, universities, and consultants). The government proposal selection process excludes individuals or companies that do not participate for many reasons (e.g. complexity of the proposal and contracting process, cost).*
- ***Creativity*** *– only the performance of an idea counts, no matter how "outside the box" it may seem. Throughout history, many prize winners have demonstrated a great ability to imagine, build and demonstrate technologies that were "non-traditional", including John Harrison (solving what was thought to be an astronomical problem with a mechanical timepiece solution).*
- ***Inventiveness*** *– the ability to combine existing elements to arrive at a new solution. Inventiveness can be defined as the property of taking existing components or ideas and combining them in new or different ways to create a solution. (Creativity differentiates itself as the same genesis of a new or different solution or methodology that is not based on existing ideas or components). Inventiveness is an important trait of prize winners because it is a critical skill required for problem solving in general.*
- ***Persistence*** *– never letting setbacks dampen the will to win. Prizewinners are typically not individuals who give up easily when faced with a problem whose solution is not immediately evident. One reason for the success of prize competitions often is because they feed the internal motivation within each competitor, to the limit of their psyche. People who are problem solvers tend to persist to a solution, especially when they have full ownership and control over the design and use of the solution.*
- ***Debt Relief*** *– prizes can be an important way for the winners to pay off existing bills. In general, competitors in a prize competition are not participating for the money. In some cases, however, it is about the*

money. Louis Bleriot, who became rich by manufacturing headlights for the new developed automobile industry, invested his personal profits from the company into his aviation hobby. He was on the verge of bankruptcy when he flew his No.11 aircraft across the English Channel to win the £10,00 purse in 1909.

- ***Risk Taking** – financial, professional, and even personal. Almost by definition, teams participating in a prize competition are risk takers. Because payment is not guaranteed and only happens at the end of a competition, teams often take on substantial risk. Many of the concepts promoted in the competition are previously untried or untested, so they are taking technical risks. In contrast to prize competitions as a procurement instrument, risk taking is an element that the typical government contract and grant procurement process attempts to eliminate.*
- ***Inspiration** – the feeling that "if somebody else could do it, so can I!" Prize competitions that are won can generate a lot of publicity and recognition for the winning team. Some of that publicity stimulates like-minded individuals to think that they could have done what the prize winner had accomplished. The general public tends to admire and want to emulate individuals that receive special recognition for achievement, especially when that recognition is accompanied by monetary compensation.*

There are also other spin-off benefits from the DARPA Grand Challenges and prize competitions. The U.S. and foreign automotive industries took notice after the successful 2005 DARPA Grand Challenge. Automotive companies were developing piece-meal applications to cars. In a recent article in Business Wire Ian Riches, the director of the Automotive Electronics Service said, "*More and more, competition within the automotive industry is going to be based on intellectual property and software built into vehicles, in addition to the physical design and visual appeal of the actual car. Vehicles with self-awareness, as well as ongoing situational awareness, are going to become increasingly commonplace, as high-end offerings in today's passenger cars migrate to all vehicles across the board.*"[67] The U.S. Department of Transportation (DOT) has been working on the Intelligent Vehicle Initiative (IVI) since it was introduced in 1997, which is a revolutionary part of U.S. DOT's Intelligent Transportation Systems (ITS) Program. IVI and ITS programs are focused on accelerating the development of vehicle based and infrastructure-cooperative products that will warn drivers of dangerous situations, congestion, and improve safety and enhance American driver productivity. In 2003 there were 6.3 million police reported motor vehicle accidents in the U.S. alone. These accidents resulted in over 42,000 people deaths and three million injuries. Accidents account for $230 billion in costs per year. The IVI initiative teamed partners from the private sector, public sector, universities and professional associations to prevent driver distractions and facilitate accelerated deployment of crash avoidance systems. [68] U.S. auto manufacturers are participating in the DARPA 2007 Urban Challenge because they see the direct correlation with the DARPA Urban Challenge and the concepts that DOT and the participating team members are trying to gain from the Intelligent Vehicle Initiative.

Microsoft has also launched a new robotics research group and its first ever robotics software called Microsoft Robotics Studio. This software allows either commercial or individual developers to create intelligent applications for a wide range of products.[69] Bill Gates believes that the emergence of the robotics industry will develop in much the same way that the computer business did over 30 years ago.[70] He imagines the birth of a new industry based on groundbreaking technologies that may change the world. He compares the challenges of the robotics industry to the computer industry three decades ago. Robotics companies do not have standard operating software that allows application programs to run in various devices. Consequently, each new robot is designed from scratch. He believes the trends are starting to come together and become a nearly normal part of our daily lives. Researchers are starting to find answers to complex issues pertaining to robotic technologies. The increasing availability of computing power and the miniaturization of microprocessors and electronic components coupled with a sharp decline in cost has started accelerating this effort. Additionally, hardware costs such as sensors, motors, servos, and lasers are also becoming more affordable. Robots now can be reasonably equipped with GPS positioning chips, video cameras, and other sensors that enhance their capabilities, expand processing power and storage capability.[71] Robots are also currently being used to assist soldiers in disarming roadside bombs and IEDs. There are approximately 300 of these devices currently in use in Iraq and Afghanistan by U.S. Forces. Electronics giant Samsung has recently announced that it has teamed with a Korean University to develop an armed robotic sentry that would have the capabilities to patrol the Demilitarized Zone between North and South Korea. These robots would have the capability to operate autonomously.[72]

Robotic and autonomous technologies will continue to become more common as these features become more reliable, safer, and less expensive. The application of these technologies shows substantial promise in reducing accidents related to fatigue and operator error. These technologies will continue to increase worker productivity, reduce operator stress, assist in the reduction of repetitive motion injuries, lessen the amount of operator training and create a more user-friendly operation. One of the reasons the Secretary of Defense Corporate Fellows Program (SDCFP) was created was to allow military officers the opportunity to work in a corporate environment to learn pioneering ways that private sector transforms and innovates and bring these lessons back to the DoD. My experience in this program has allowed me to understand how Caterpillar uses innovation to drive change in their markets, particularly in the robotic and autonomous ground vehicle research and development. Caterpillar has been a strong supporter of recent prize competitions participating in all of the DARPA Grand Challenges sponsoring multiple teams that have been top finishers in both competitions.

My experience at Caterpillar

As part of my Secretary of Defense Corporate Fellowship Program, I was assigned to spend a year at a U.S. Fortune 100 Corporation—Caterpillar Inc. The experience allowed me to work and learn in the corporate environment. I was able to observe how an exceptional company solves complex customer issues in the development of new products. My assignment to the New Product Introduction Directorate, Technology and Solutions Division provided unique insights and an understanding how Caterpillar uses Research and Development and New Product Development to solve difficulties customers often face in rugged working conditions. These conditions are similar to the military, as it has to operate in 24 hours a day, 7 days a week. I also was able to conduct extensive research for this paper with Caterpillar researchers that have been directly involved in the recent DARPA prize competitions and other robotic and autonomous R&D. This unique opportunity provided me with valuable insights as to the possibilities for leveraging the commercial sector and assisting in the development of robotic and autonomous technologies for the Armed Forces and the U.S. government.

Caterpillar is the world's largest manufacturer of construction and mining equipment, diesel and natural gas engines and industrial turbines. They are a technological leader in construction, transportation, mining, forestry, energy, logistics and electric power generation. Caterpillar currently employs over 90,000 people in 40 countries and has a global team of over 200,000 individuals including employees, dealers and suppliers. The global enterprise sells over 500 products in nearly 200 countries with approximately 52 percent of sales and revenues coming from countries outside the United States.[73] In 2000, Caterpillar set a bold goal to burst through the $20 billion stall point and increase sales by a staggering 50 percent in six years. Thanks to the dedication of their employees and the discipline of a 6 Sigma process that drove fact-based and data-driven decision making they achieved this bold goal two years ahead of schedule. Caterpillar is a Fortune 100 Company and a Fortune 500 Global Company that achieved sales and revenues of $41.52 billion for 2006. Caterpillar has been number one in stockholder returns for the Dow 30 companies over the last five-years.[74]

Caterpillar is defined by its legacy of innovation. Caterpillar invested over $4 million in R&D each working day for a total of $1 billion in 2005. Caterpillar has hundreds of Ph.D. scientists and generated more than 2,500 patents in the last five years alone.[75] The company is working on robotic, semi-autonomous, and autonomous research for vehicles and machines and has been for several decades. The company is an industry leader in Research and Development and innovation and has accumulated over 100,000 test miles on large autonomous mining vehicles (100 ton) that date back to the 1990s (which were ahead of market needs at that time).[76]

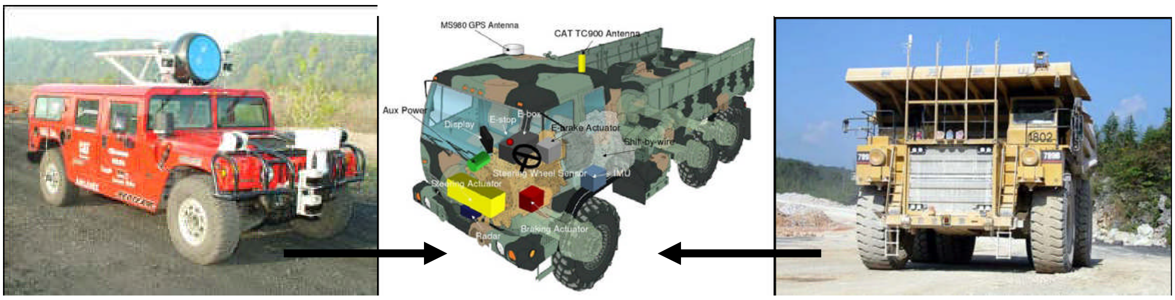
The true test of the product's reliability though was when it faced the test of competition. Caterpillar sponsored three of the top five teams for the 2005 DARPA Grand Challenge finishing second, and third, and fifth (two teams from Carnegie Mellon University and one team from Oshkosh). Caterpillar teamed with Carnegie Mellon University, SAIC, and Boeing to design and provide technology for two vehicles (Red Team and Red Team Too), which finished second and third in the 2005 DARPA Grand Challenge.[77] Caterpillar also sponsored Team TerraMax, the fifth-place vehicle fielded by Oshkosh Truck Corporation, (a company that provides off highway trucks to the military which use Cat engines). On June 2, 2006 Oshkosh announced that it is in the final stages of development of an unmanned version of its Palletized Load System (PLS) vehicle for the U.S. Army. This technology was unveiled at their U.S. Army Tactical Wheel Vehicle Demonstrations in Yuma, Arizona. Oshkosh demonstrated real world mission applications of the technology with autonomous trucks transporting cargo between destinations over seven miles apart.[78] These technologies were tested and validated in the 2004 and 2005 DARPA Grand Challenge races.

Robotics professor Dr. William "Red" Whittaker led the two teams from Carnegie Mellon University. "Because Caterpillar is in the business of developing innovative equipment to perform in rugged work conditions," Whittaker said, "this partnership made sense." Caterpillar also embedded one of their engineers with the team to work on the electronic systems and other Caterpillar technology. Caterpillar technology such as the drive-by-wire steering, sensing, software, electronics engine control, electrical power supply and air-conditioning for the on-board navigation, control and guidance systems were used on both vehicles from Carnegie Mellon Tartan Racing Team for the 2005 DARPA Grand Challenge.[79] The close collaboration included Caterpillar Engineer Joshua Struble who led the "Red Team" electronics engineers. He actually moved to Pittsburgh to fully embed with the other engineers from sponsors and members of the team. Josh provided technical expertise to write the new software and to develop new power systems for the teams.[80] One of the major benefits from the competition is the two-way collaboration that was developed among the teams. The teams were comprised of embedded engineers from the major sponsors, Caterpillar, Boeing, SAIC, and Carnegie Mellon University. The team divided responsibilities into areas such as hardware, software, electronic, testing and evaluation, and overall integration. This collaboration helped bring reality to the basic research on robotics that Carnegie Mellon and others have conducted over the past several decades.[81]

Through their willingness to test their new products in advanced technology prize competitions like the DARPA Grand and Urban Challenges, leaders at Caterpillar were able to stand behind their innovations as well as adjust and respond to necessary changes or needed improvements. This kind of commitment to improve complex technologies before the DoD purchases such systems, translates into a more reliable product out in the field—in this case the battlefield. Immediately following the 2005 DARPA Grand Challenge the "Red Team" used their efforts to provide a Leader Follower Autopilot System that leverages existing technologies that were used in the 2004 and 2005 DARPA Grand Challenge for development on other vehicles. The focus of this effort was to leverage technologies that Caterpillar and Carnegie Mellon University had developed over the past two decades from their experience with autonomous mining vehicle research and development and the more recent experiences from the 2004 and 2005 Grand Challenges.

Figure 7 below illustrates how Caterpillar and the "Red Team" have leveraged their experience in the application of autonomous technologies to develop the Leader Follower AutoPilot System. [82]

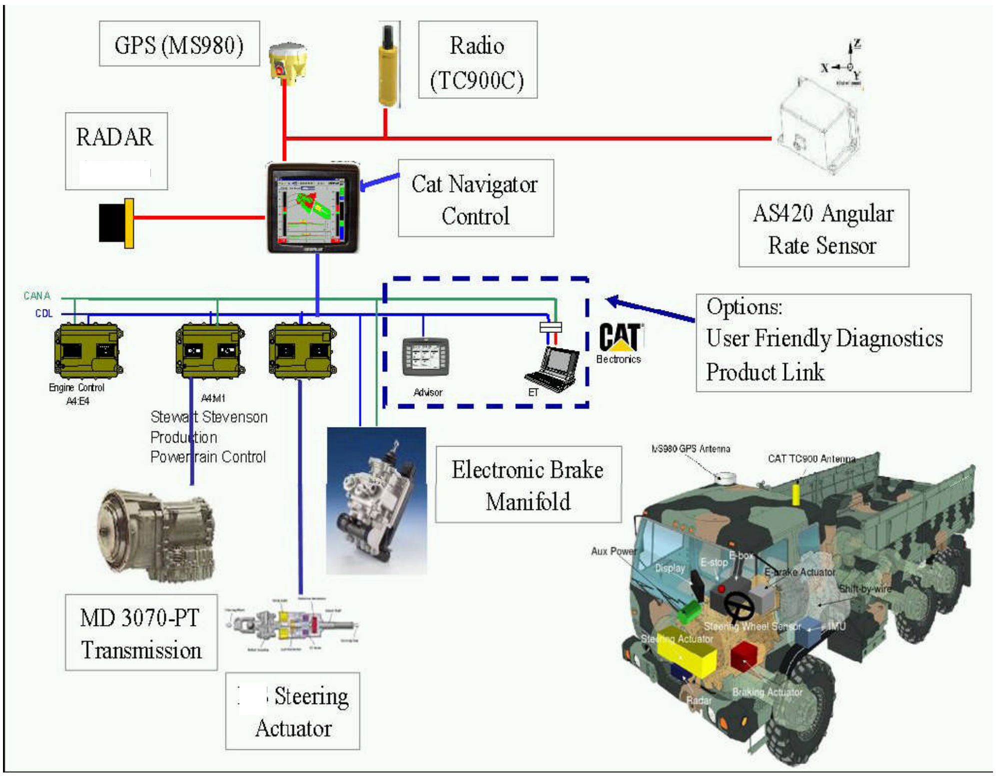
Figure 7



Source: Caterpillar Inc. and Armor Holdings, Tactical Vehicle Systems, December 2005
"Reprinted Courtesy of Caterpillar Inc."

The Robotic Leader Follower system was proposed for use with the Army's Family of Medium Tactical Vehicles (FMTV), but it has not been developed or validated. As proposed, the system would provide a capability for each Family of Medium Tactical Vehicles (FMTV) to follow the lead vehicle based on GPS signals. The system would have the artificial intelligence to determine if it should follow a preplanned route or follow the lead vehicle safely. This would allow vehicles in serial for a convoy to link up, control speeds and establish appropriate convoy intervals. The vehicles would be further equipped with adaptive cruise control that allows for automatic convoy speed adjustments to avoid accidents. The self-driving FMTV's would be equipped with accurate and reliable GPS systems with inertial backups. The auto pilot system is based on proven software and Caterpillar's industry-proven rugged commercial hardware.[83] These features have direct implications for the tasks that soldiers are being required to perform in the harshest conditions, in a dangerous and complex operational environment for extended periods of time. This capability has exceptional potential to save soldiers lives, reduce the logistical burden by reducing the number of soldiers needed to operate a convoy and to make the convoy operations less grueling for the operators. Caterpillar already has autonomous and robotic features in production with proven systems already in use on multiple products that are performing in harsh environments such as the construction and mining industries. Caterpillar also has worldwide support capabilities for their products and service. Their extensive dealer networks coupled with their world-class logistics system would ensure rapid support and sustainability of this Leader Follower system.[84] Figure 8 below illustrates the various commercially available components that comprise the Leader-Follower Autopilot System.[85]

Figure 8



Source: Caterpillar Inc. and Armor Holdings Tactical Systems, December 2005 "Reprinted Courtesy of Caterpillar Inc."

Source: Caterpillar Inc. October 2006 "Reprinted Courtesy of Caterpillar Inc."

Caterpillar is also continuing development of the connected jobsite that in concept is similar to what the Army is developing with the FCS program, made up of 14 interconnected systems that create a 'system of systems'. Caterpillar's connected jobsite concept will leverage machine position sensing technology which is essential for advanced applications such as product tracking and monitoring, machine scheduling, dispatch systems and autonomous operation. On-board orientation sensing and implement position sensing can be used to improve machine controllability, operator comfort, and to automate portions of a work cycle. The potential for the connected jobsite is virtually endless for both commercial and military applications. This information is real time and provides the capability to simultaneously orchestrate an efficient workflow, maintenance operations, safety, production effectiveness, tracking and coordination of equipment for an entire job site or multiple jobsites around the world. These technological capabilities allow jobsite managers to remotely monitor the status of their equipment in real time. In the future, remote operation of equipment may be possible through the rapidly developing communications technologies that will allow operators to tele-operate equipment in dangerous and oftentimes isolated locations from the comfort of their office or home. The applications of this technology for the military are vast and support the vision and goals of the Army Future Combat System. The photo above illustrates some of the capabilities of augmented reality and how these capabilities can be applied for the remote control operation of Caterpillar's D-10 track-type tractor.[86]

Caterpillar has a joint venture with Trimble that leverages the availability of GPS and applies that technology to their machines based on machine and guidance systems for multiple product families. Systems and Controls Research uses positioning systems extensively during the development of autonomous systems and site management tools, such as the Computer Aided Earthmoving System CAES™ (shown below).[87]

Source: Caterpillar Inc. 2001
"Reprinted Courtesy of Caterpillar Inc."

Caterpillar has developed other autonomous technologies such as AutoCarry™ that automate portions of a work cycle. This autonomous capability allows operators to perform more efficiently in dozer production operations. It boosts dozer production by automatically controlling blade height during the carry portion of the dozing cycle. Consequently, consistent, optimum blade loads are achieved for each pass. For less experienced operators' there is up to a 15 percent productivity increase. The spin-off benefits of this technology application could reduce training time for new operators and also improve machine controllability and operator comfort and safety. Additionally, the operator is able to attain consistent loads regardless of the time of day or weather conditions. The U.S. Army Tank and Automotive Command (TACOM) is currently exploring autonomy to lighten operator workloads. This is critical in the complex environments that many of our warfighters find themselves in today and for the future. The explosion of electronic functions has made the operator environment more comfortable, however, it has also placed additional requirements on operators that are already stressed. Researchers are now focused on how to allow operators to better manage situational awareness, and apply the many tools that are now being developed for their vehicles while not losing sight of the basic task of moving from Point A to B. "*We are concentrating on information overload and ease of use",* said Celeste Corrado, Human-Computer Interface Business manager at Lockheed Martin Advanced Technology's Artificial Intelligence Lab.[88] The goal of this research is to help reduce operator workloads and let autonomous intelligent systems handle portions of the overall tasks. The major challenge is to ensure that these autonomous features are safe. Caterpillar is doing similar research to improve safety, reduce operator workload and improve overall efficiency and effectiveness. These commercial autonomous capabilities should be fully leveraged to help solve similar problems that reside in the robotic and autonomous vehicle research community. These Caterpillar examples of innovative products offer a sampling of items that would be useful for military purposes. The military needs products proven ready for use-lives are at stake. DoD can leverage the results of private sector R&D with minimal investment through the use of prize competitions. Recent prize competitions have brought to the forefront many of the research and development initiatives that have been going on in different segments of the research community for robotic and autonomous technologies over the past several decades.

Conclusion

Innovators using prize competitions to accelerate the development of complex and slowly maturing technologies create a synergy that benefits the DoD and by extension soldiers throughout the world. While originally a scientific term, the word synergy has several meanings and in this case could translate into saving lives. The value of research prizes through competition to spur innovation promotes synergy to bring together very diverse individuals and capabilities to work out seemingly unsolvable and complex technical issues. Using research prizes to spur innovation allows for the widest possible range of approaches. The use of competitions removes some of the innovation inhibitors that can be found in standard research and development communities due to the established cultural and deeply developed and embedded organizational processes that work effectively for sustaining technologies but are counterintuitive for developing disruptive technologies.

Throughout the history of prize competitions, it has been proven time and time again that additional funding will be devoted to the research as part of a competition for a substantial prize award than is available if you actually win the prize. DARPA indicates that for every dollar in the first $1 million prize for the 2004 DARPA Grand Challenge approximately $65.00 in investment was attracted by competing teams and their sponsors that sought to attain the Grand Challenge goals. The resulting return on investment for this competition would be considered a huge success for any company. DARPA spent approximately $13 million on the race in 2004. It estimates that participants in the race laid out four to five times that amount in the development of their vehicles. Carnegie Mellon President Jared Cohon said that the “Red Team” vehicle that participated in the Grand Challenge cost approximately $3 million, which was contributed by corporate sponsors.[89] A consistent management theme exists for Research and Development (R&D) organizations concerning how to better use scare resources to maximize R&D returns. Prize competitions basically create the conditions to outsource R&D efforts by augmenting existing R&D efforts with desirable incentives. This strategy may or may not yield substantial R&D savings, but can provide a tremendous amount of information that may not be otherwise be obtainable, even if the prize is never won.[90] Moreover, prize competitions generally cost a small fraction of what a contract would be worth to attain similar results. The financial risk of funding R&D is shared with the prize competitors instead of it resting solely on the U.S. government. The government is not required to pay the prize money unless a competitor actually meets all of the prize competition rules.[91]

Dr. Peter Diamandis is the individual responsible for the recent revival in the use of prizes as incentives for breakthrough technologies. His efforts conceived the X-Prize, a $10 million award for the first privately built suborbital space flight that was initiated in 1996. He says, "*If you look at prizes across the board, they vary in collective expenditures from about 10 - to 40-fold beyond the prize value itself*." Part of the momentum for the successful development of a radical innovation may be more about the accomplishment of winning the competition and the prize rather than the money. "*It is critical that the public be excited*," he says. "*You can't have a prize for just a widget by itself. It has to be about people-it's never about the widget*." [92]

The most successful prize competitions engage the public, media, academia, industry and diverse enthusiasts in order to create a synergistic environment to allow the full exploitation of the prize culture characteristics. There is a certain level of excitement that builds on the competitive spirit and characteristics of people and organizations that are drawn to these types of competitions. Prize winners are individuals who are driven to continue to press on even when faced with seemingly impossible challenges. These competitors feed on the internal motivation within each individual and team to persevere to a solution that is not immediately evident.[93] The DARPA Grand Challenge has been extremely successful in drawing in participants that would normally not do business with the U.S. government through normal grants and contracts for R&D.

Competitions like these are also important because they show how the application of these new disruptive technologies and integrated solutions work in a real-time complex environment. Both Grand Challenges required tactically relevant speeds to accurately replicate the actual conditions that soldiers encounter when they are out driving in convoys. Failures are also beneficial to determine exactly where a product's technological maturity level truly lies. This was the case in the DARPA 2004 Grand Challenge when not one vehicle made it any farther than eight miles. However, in less than two years, five autonomous vehicles successfully completed the 132-mile race while four vehicles completed the race in under the 10 hours time requirement.

The U.S. government must ensure that there are strong links between the military, scientific communities, academia, and enthusiasts who normally do not interact with the U.S. government or the industrial communities so that complex and slowly maturing technologies can be rapidly developed to deal with the asymmetric threats that attempt to undermine our national security around the world. Advanced technology prize competitions have been used throughout history to stimulate innovation and accelerate the development of complex and slowly maturing technologies. Prize competitions should, if developed and implemented properly, complement research grants and contracts, not replace them. The focus should remain on complex and slowly maturing technologies to ensure that prize competitions focus on truly high-risk high-payoff technological innovations. This strategy provides substanital mutually supporting benefits for the military and both the public and private sector to stimulate innovation and accelerate the development of slowly maturing technologies.

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